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COMPARISON OF TWO HEAD-UP DISPLAYS IN SIMULATED STANDARD AND NOISE ABATEMENT NIGHT VISUAL APPROACHES

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For both standard and noise-abatement approaches, the situation display provided greater glidepath accuracy in the initial phase of the landing approaches, whereas the command display was more effective in the final approach phase. Glidepath accuracy was greater for the standard approaches than for the noise abatement approaches in all phases of the landing approach. Most of the pilots preferred the command display and the standard approach. Substantial agreement was found between each pilot's judgment of his performance and his actual performance.

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SUMMARY

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For both standard and noise-abatement approaches, the situation display provided greater glidepath accuracy in the initial phase of the landing approaches, whereas the command display was more effective in the final approach phase. Glidepath accuracy was greater for the standard approaches than for the noise abatement approaches in all phases of the landing approach. Most of the pilots preferred the command display and the standard approach. Substantial agreement was found between each pilot's judgment of his performance and his actual performance.

INTRODUCTION

A suitable guidance system for VFR non-ILS conventional landing approaches has been the subject of considerable research. Of recent concern is the development of an accurate guidance system for two-segment noise-abatement approaches. In the two-segment approach, the aircraft approaches on a higher-than-normal glide slope and then makes a transition to the standard glide slope in time to stabilize prior to landing. To fly these approaches accurately, a pilot requires glide slope guidance for both the upper segment and the lower segment. Several systems have been shown to be feasible: (1) the combined use of distance measuring equipment (DME) and barometric altimeter signals (ref. 1), (2) the use of area navigation equipment (ref. 2), and (3) a specified airspeed descent from a DME fix (ref. 3). Head-down instrumentation was used with all of these systems, and ground-based electronic approach aids were necessary. With the use of a head-up display (HUD), neither an area navigation system nor a colocated DME is needed to provide the required guidance.

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The objective of a recent flight and simulator evaluation (ref. 4) was to determine the acceptability of a HUD as an aid to the pilot during VFR standard and noise-abatement approaches. Command and situation head-up displays were evaluated. Both displays showed promise in providing glide slope tracking accuracy in both standard and noise-abatement approaches. The simulator results also showed substantial increases in glidepath precision over the approaches flown without the HUD. These results were similar to the results of two other simulator studies (refs. 5, 6), which showed a large improvement in glidepath tracking precision when a HUD was used during VFR landing approaches. However, the initial study (ref. 4) did not resolve whether differences existed between the command and situation displays in either glidepath precision or pilot workload. The basic difference between the situation and command displays is the method by which the appropriate pitch corrections are determined by the pilot. When using the situation display, the pilot determines pitch corrections through interpretation of the position and attitude of the aircraft relative to the glide slope at a particular time. With the command mode, the computer determines the needed flight path angle corrections and displaces a symbol that commands the pilot to change the aircraft pitch attitude.

The present simulator study was designed to focus directly on the relative merits of the two types of head-up displays during both standard and noise-abatement approaches. All of the HUD information presented to the pilot in this study was independent of ground navigational aids.

METHOD

Pilots

Eight currently employed airline transport pilots, each having a minimum of 1500 hr of multiengine jet and at least 300 hr of simulator and instrument flight time, participated in the study. Three major air carrier corporations and three types of jet transports were represented by the flight experience of two Captains, five First Officers, and one Second Officer.

Apparatus

A fixed-base transport simulator having a full-size commercial air carrier cockpit was used in this experiment. An electronically displayed night visual scene and the HUD symbols were viewed through a 50.8 × 50.8 cm (20 × 20 in.) collimating lens situated 76.2 cm (30 in.) in front of the pilot above the glare shield. The normal 28° field of view for the display system was restricted in the vertical plane to 24° by the glare shield and overhead panel.

Aircraft controls and dynamics– The simulator had a hydraulic control-loader system, which allowed use of standard trimming and flight control procedures. Manual throttle control was used to maintain an airspeed of 70 m/sec (145 kts). DC-8 aircraft dynamics were programmed on a digital computer.

External night scene– A computer graphics system generated the night scene and HUD symbology. The light sources were viewed by the pilot on a 53.3 cm (21 in.) cathode-ray tube through the collimating lens. A total of 1167 points of light provided a three-dimensional perspective

simulation of the Municipal Airport in San Jose, California (fig. 1). Two light bars consisting of three lights each were located on each side of runway 30L at 305 m (1000 ft) past the runway threshold. The locations of the light bars depicted the ground plane intersection (runway aim point) of the 3° glide slope. The aim point for the 6° glide slope in the two-segment noise-abatement approach was the first light bar of the approach light system located 893 m (2930 ft) before the runway threshold. Since the light bar was elevated, the ground level angle apex was located 832 m (2730 ft) from the threshold. The night scene included a strobe light for runway 30L and flashing obstruction lights.

Head-Up Displays

The HUD presentations were superimposed on the night scene. Horizontal and vertical field of view limits were 12° for both displays. The situation display contained two horizontal glidepath angle bars, which were fixed at the −3° and −6° positions on dual glidepath angle scales (fig. 2). The glidepath angle scales were gyrostabilized so that the zero point on the scales always referenced the actual horizon. This display incorporated an aircraft pitch attitude symbol that moved independently from the fixed bars. The fixed bars indicated the ground contact point of the 3° and 6° glide slope angles. The pilot maintained the appropriate glide slope angle to the desired aim point by overlaying it with the fixed bar. A movement of the fixed bar from the aim point indicated the direction of the needed pitch correction to track the desired glidepath angle. The magnitude of the pitch correction was determined by the pilot's interpretation of wind effects and the aircraft position and movement relative to the glide slope. Figure 2 indicates that the aircraft is low, since the −3° fixed bar is superimposed on a point short of the threshold. However, the pilot has made a pitch correction as indicated by the near-level position of the aircraft attitude indicator.

The command display incorporated the identical presentation and function of the glidepath angle scales (fig. 3), but with the addition of a single horizontal bar called a flight path bar. The flight path bar furnished wind compensation information through continuous computer calculation of the ground flight path angle. Ground flight path angle was derived by dividing vertical velocity by ground velocity. The signal that drove the flight path bar was calculated by multiplying ground flight path angle by a gain less than one and adding a constant so that when the aircraft was on a 3° glide slope angle and had a −3° ground flight path angle, the flight path bar was aligned with −3° on the scales. Adjusting the aircraft pitch attitude so that the bar overlayed the desired aim point caused the aircraft to fly to and then along the 3° glide slope to that point. In this way, the magnitude of the needed pitch corrections was indicated by the flight path bar position and was not dependent on an interpretation of wind effects and aircraft position by the pilot. Figure 3 shows that the aircraft has descended to a 2° glide slope. A correction is being made by holding the flight path bar on the runway aim point. This procedure will result in the eventual return to the 3° glide slope. Use of the command display in the noise-abatement approach resulted in an initially steep and slightly curved upper segment trajectory, which gradually changed to 3° as the standard glide slope was intercepted (fig. 4).

Measurement areas– Six measurement areas (MAs) are depicted in figure 4. Each MA was 1400 m (4592 ft) in length and contained eight data-collection points (DCP) at which deviations from the glide slope were measured. These points were equally spaced at 200 m (656 ft) intervals. An area of increasing tail wind shear, bounded by the DCPs located at 1400 and 400 m (4593 and 1312 ft) from the runway aim point, was contained within MA 4. MA 1 and MA 1a were placed at

equal distances from their respective ground level aim points, as were MA 2 and MA 2a. Glide slope angle measurements were taken in MA 3, and height and workload measures were taken in MAs 1, 1a, 2, 2a, and 4. This arrangement of MAs furnished an equivalent basis for extracting comparative data in the initial, center, and final sections of both types of landing approaches.

Winds– The following three wind conditions were used: (1) zero wind speed throughout the approach; (2) zero wind speed to 1400 m (4592 ft) from the runway point at which distance an increasing tail wind shear rate of 0.13 m/s per meter (8 knots/100 ft) of decreasing altitude was introduced and continued to touchdown; and (3) varying wind conditions including changes in speed, direction, and shear gradients. Light turbulence was present in all approaches using random gusts at 0.1 rad/s rms in the three rotational axes and 0.03 m/s (0.1 ft/s) rms in the three aircraft body axes.

Procedure

Sequence of events– The pilot depressed a control button to start each standard approach at 10,124 m (33,217 ft) from the runway aim point. He started each noise-abatement approach at 11,237 m (36,867 ft) from the same point. The simulated aircraft was flown in level flight for approximately 20 s before reaching the glide slope intercept point. The glide slope intercept point was identified as follows: (1) in the noise-abatement approach with situation display, by the superposition of the 6° fixed bar over the 6° aim point; (2) in the noise-abatement approach with command display, by the convergence of the 6° aim point with the −6° indices of the glidepath angle scales; (3) in the standard approach with the situation display, by the superimposition of the 3° fixed bar over the runway (3°) aim point; and (4) in the standard approach with the command display, by the convergence of the runway aim point with the −3° indices on the glidepath angle scales.

The final landing configuration with full flaps was used throughout all approaches. The approaches were flown to touchdown with an additional 5 s time allowance for a partial landing roll on a 2268 m (7440 ft) runway. The elapsed time for each approach was about 2.5 min, depending on the wind condition presented.

Training phase– After receiving instructions and equipment familiarization, each pilot flew a minimum of eight training approaches for each of four display/approach conditions (table 1). These were presented in blocks of four approaches each. Each approach incorporated a random order presentation of wind conditions. The zero wind condition (1) was presented in one approach, wind shear condition (2) in another, and varying wind condition (3) in the remaining two. Following each training approach, the pilot was presented a graph on the display screen of his approach trajectory relative to the reference trajectory. Before a pilot could progress to the experimental phase, he was required to fly the simulated aircraft within 5.2 m (17 ft) of the glide slope at 1400 m (4592 ft) from the runway aim point in any three of the four approaches of two consecutive approach blocks. When necessary, additional blocks of training approaches were flown until the training requirement was satisfied. This procedure resulted in a minimum of 32 practice approaches (8 approaches × 4 display/approach conditions) flown by each pilot.

Experimental phase– Each pilot completed both the training and experimental phases with one display/approach condition before proceeding to the next of the remaining three. After meeting

the training requirement, each pilot flew 10 approaches for each condition, presented in two blocks of five approaches each. Wind conditions (1) and (2) were presented twice and wind (3) once in random order within each block of approaches. The zero wind condition (1) and wind shear condition (2) differed only in MA 4. There was no wind in MAs 1, 1a, 2, and 2a with wind conditions (1) and (2). To avoid pilot anticipation of these zero wind conditions, the varying wind condition (3) was presented on one approach within each of the two approach blocks. The data from this approach were then discarded, leaving eight data-collecting approaches for each of the eight pilots, for a total of 64 approaches under each of the four display/approach conditions. Transfer effects were minimized by counterbalancing the presentation order of the conditions (table 1).

Performance measures– A mean absolute height error was calculated for each pilot within each MA, display/approach condition, and wind condition. These data were used for the statistical tests. The mean height errors for the noise-abatement approaches were obtained from MAs 1, 2, and 4, whereas those for the standard approaches were obtained from MAs 1a, 2a, and 4. A mean altitude at each data-collection point in MAs 1 and 2 was computed after all approaches were completed. This computed mean altitude substituted for the lack of a standard reference glide slope in the upper segment of the noise-abatement approach with command display. In these MAs, the height errors were made relative to those computed mean altitudes. A second set of height errors relative to mean altitudes was obtained in MAs 1a and 2a to provide equivalent source data for comparing standard approaches with noise-abatement approaches in these MAs. During each noise-abatement approach, the lowest glide slope angle to which the pilot descended in MA 3 was measured to determine if he had undershot the 3° glide slope. Workload measures were recorded as the standard deviation of the rate of fore and aft control wheel movement.

Quantitative and subjective data comparison– Subjective data were acquired after the experimental approaches had been flown by having each pilot complete a questionnaire (appendix A). In statements 1–4, the pilots indicated their preferences for the displays and types of approaches through comparisons of four combinations of these two variables. Each pilot judged how he thought he had performed under each display/approach condition in the areas of workload and glidepath precision. Safety also was judged in statement 4d, which compared the two noise-abatement approaches.

RESULTS AND DISCUSSION

Performance Under Zero Wind Conditions

The mean height errors for the eight pilots in each MA are summarized in table 2. Since wind shear was encountered in MA 4 in half of the approaches flown, only the approaches flown under the zero wind condition (1) were used to calculate the mean height errors presented for MA 4. The data for MAs 1, 1a, 2, and 2a represent the mean height errors for all of the data approaches flown because wind shear was not encountered in these MAs.

To determine the differences in pilot performance between the displays and types of approaches under zero wind conditions, a four-way analysis of variance, 2 (situation, command) X 2 (standard, noise abatement) X 3 (MAs) X 8 (pilots) was performed. The analysis revealed

significant differences in all but one main effect (type of approach, $F(1,7) = 4.45$, $p < 0.10$) and all but one interaction (displays X type of approach, $F(1,7) = 4.94$, $p < 0.10$) as follows: (1) displays, $F(1,7) = 8.97$, $p < 0.025$; (2) measurement areas, $F(2,14) = 13.09$, $p < 0.001$; (3) displays X MAs, $F(2,14) = 9.15$, $p < 0.005$; (4) MAs X type of approach, $F(2,14) = 6.37$, $p < 0.025$, and (5) displays X MAs X type of approach, $F(2,14) = 4.84$, $p < 0.05$.

The significant difference between displays appears to be closely related to the large performance differences between the two displays that were recorded in MAs 1 and 2 in the noise-abatement approaches (table 2). Although not as pronounced, a similar relationship is seen in MA 1a in the standard approaches. These differences in mean height errors between the two displays decreased and then reversed as the landing point was approached. Note the smaller mean height error for the command mode in MA 4, the final portion of both the landing approaches. A three-way analysis of variance, 2 (displays) X 2 (types of approaches) X 8 (pilots), using the data obtained in MA 4, revealed a significant difference between the displays, $F(1,7) = 11.70$, $p < 0.025$, and the two types of approaches, $F(1,7) = 6.24$, $p < 0.05$. Interaction was not significant. These analyses in conjunction with table 2 demonstrate the greater glide slope accuracy attained with the situation display in the earlier portion of either type of approach and that of the command display in the final section of the approaches. The significant difference in the MAs' main effect also is indicated in table 2 in that a consistent decrease in mean height errors occurred as the aircraft progressed through the MAs toward the landing point.

Note that the standard deviations for the command display in MAs 1a, 1, and 2 are disproportionately large (table 2). These values are thought to be the result of the design of the command display, which did not have a bar reference for determining the glide slope intercept point as did the situation mode. Instead, the pilot referred to the $-3°$ or $-6°$ indices on the glide slope angle scales situated laterally from his view of the runway aim point. To intercept the glide slope properly requires precise timing of aircraft pitch and power changes relative to a well-defined glide slope intercept point. In the training phase, several pilots experienced difficulty in determining the exact glide slope intercept point when using the command display. When this occurred, usually the initiation of the approach descent was either delayed or begun too early. In either case, the glide slope interceptions occurred at varying distances along the approach path. Occasionally, the interception of the glide slope did not occur until after the aircraft passed through MA 1, or MA 1a, which increased the variability of the mean height errors in these MAs.

Performance Under Wind Shear Conditions

The mean height errors for each wind condition in MA 4 and each pilot served as the data for determining the effectiveness of each display in compensating for wind shear effects. All of the approaches flown are represented by these data, which are summarized in table 3.

To evaluate performance differences between the two displays under wind shear conditions, a four-way analysis of variance, 2 (situation, command) X 2 (zero wind, wind shear) X 2 (standard approach, noise abatement approach) X 8 (pilots), was conducted. The analysis revealed significant differences in all main effects and one interaction (wind condition X type of approach) as follows: (1) Displays, $F(1,7) = 11.52$, $p < 0.025$; (2) wind condition, $F(1,7) = 123.60$, $p < 0.001$; (3) type of approach, $F(1,7) = 10.89$, $p < 0.025$; and (4) interaction, $F(1,7) = 12.70$, $p < 0.01$. All other interactions were nonsignificant.

The results of the analysis in conjunction with table 3 clearly indicate that a significant decrease in mean height errors occurred with use of the command display over that of the situation display during the approaches in which the increasing tail wind shear was introduced. Under zero wind conditions, the aircraft's flight path through an air mass was essentially the same as the glide slope angle with most perturbations being caused chiefly by pilot control inputs. When changes in wind occurred, the flight path through the air mass had to be changed in order to maintain the ground-referenced glide slope approach angle. To do this, the pilot changed the power setting and aircraft pitch angle. Using the situation display, the magnitude of these changes was determined by pilot interpretation of the visual situation presented by the display symbology. With the command display, the computer processed the same information 20 times/s, and when the calculations were complete, the answer as to how large of a pitch change was to be made was presented to the pilot by a displacement in the flight path bar position. By maintaining the flight path bar on the runway aim point, the magnitude of the needed pitch correction was automatically determined and compensated for. The data clearly show that when changes in the flight path were necessary due to changing wind velocities, the rapidity and accuracy of the computer surpassed that of the pilot in determining the necessary amount of pitch change.

It was expected that pilot performance would deteriorate under wind shear conditions with either display and this was demonstrated by the large F (F = 123.60) for the wind conditions main effect. The onset of wind shear was gradual, with only subtle changes in visual cues. Usually, their accumulation must become gross before the pilot recognizes that the aircraft is making a fairly rapid departure from the glide slope. That the pilot's recognition threshold for wind shear is not reached immediately following its initiation is evident in table 3, wherein the mean height errors are shown to increase for both displays under the wind shear condition.

The data in table 4 support the statistical significance of the type of approach main effect and the interaction effect. When the mean height errors for the two types of approaches relative to the wind condition (zero wind, wind shear) were calculated, the mean height errors during the noise abatement approaches were seen to increase over those of the standard approaches regardless of the wind condition presented. However, this difference in performance may be related to the higher mean glide slope angle (3.01°) recorded in MA 3 during the noise-abatement approaches. The mean glide slope angle for the standard approaches was 2.95°. At 2100 m (6890 ft) from the runway aim point this difference is 2.2 m (7.2 ft). It appears that this distance, although reduced as the touch-down point was approached, may have affected the height errors obtained between the two types of approaches. Similar differences between the two types of approaches are seen in the summarized data of table 2. These data (tables 2 and 4) reveal that in all three sections of the approach path (initial, center, and final), the mean height errors from the glide slope and the standard deviations were greater for the noise abatement approaches than those for the standard approaches. This occurred in both zero wind and wind shear conditions.

True height errors, which make a distinction between height errors above and those below the glide slope, were used to further investigate the differences between displays when wind shear is encountered. The flight paths for each display are portrayed by plotting the mean true height errors and standard deviations incurred at each of the eight data-collection points in MA 4 in figure 5. The reference data represent the Category II, ILS tracking accuracy requirement established by the Federal Aviation Agency (ref. 7) for guidance systems used in IFR landing approaches. The directive states that the aircraft must be within ±3.7 m (12 ft) of the glide slope at 30.5 m (100 ft) altitude. These criteria convert to a 0.3° glide slope deviation angle relative to the optimum glide

slope. It is presented in equal scale with the true height error data to furnish a pictorial reference as to the relative accuracy of the two displays. The data in figure 5 represent only those approaches under each display in which wind shear was encountered. This resulted in 64 true height errors (8 pilots × 8 approaches, 4 standard + 4 noise abatement) serving as the data at each DCP.

In the zero wind portion of MA 4 (DCPs 18 to 14), the mean height errors for the command display consistently converged with the glide slope. This is not apparent with the situation display and may be related to the influence of the higher mean glide slope angle recorded in MA 3 during the noise-abatement approach using the command display. The mean glide slope angle in MA 3 for the noise-abatement approach with command display was 3.04°, whereas for the situation display it was 2.98°, the latter being much closer to the 2.95° mean glide slope angle of both standard approaches. This point (DCP 18) is where the situation display ceases to be the more effective display with the zero wind condition as previously indicated.

By describing a line between the means from DCP 14 to DCP 4, the gradual descent incurred by the introduction of the wind shear can be seen in the flight paths for each display. With the command display, the descent ceased and a corrective movement back toward the glide slope occurred prior to reaching DCP 6. This did not occur with the situation display until some point past DCP 6 was reached, indicating the capability of the command display to provide earlier recognition of and correction for the wind shear.

The greater standard deviation for the command display at DCP 18 may have been influenced by the previously indicated operational design of the command display. The differences between displays in the standard deviations reached a magnitude of two at DCPs 12, 10, 8, and 6. A lesser command display standard deviation also is seen in table 3 in which mean absolute height errors per pilot were used for the data. The standard deviations represented by the vertical bars at each DCP in figure 5 show that the use of the situation display caused the simulated aircraft to exceed the lower reference data at DCPs 6 and 4 most of the time. This seldom occurred when the command display was used.

Glide Slope Angular Deviations and Workload Data

There was no difference between displays during standard approaches in the average of the lowest glide slope angles to which the pilots descended in MA 3. They were both 2.95°. However, for the noise abatement approaches, the same angular measure was 2.98° for the situation display, and 3.04° for the command display. No descent more than 0.3° below the glide slope occurred during the experimental phase. In the simulator, the possibility of an undershoot during transition from the upper segment of the noise abatement approach to the lower segment appears to be of no consequence.

The workload measure, the standard deviation of the rate of fore and aft control column movement, showed that the overall (all MAs) command display mean workload was 90 percent of that incurred with the situation display. The standard approach with the command display yielded the least workload. With each display, the greatest workload was recorded for the noise abatement approaches using the overall mean workload measure.

Subjective and Quantitative Data Relationships

The responses to statements 1 through 4 and questions 5 and 6 on the pilot questionnaire were tabulated and entered in table 5. Of the two approach systems listed in each of the statements, more than half of the pilots expressed their preference for the system that was measured to be the most precise. Seven of the eight pilots preferred both the standard and noise-abatement approaches with the command display over those flown with the situation display (statements 1 and 4). These preferences correlated with each pilot's individual best performance for seven of the eight pilots in the standard approaches and for six pilots in the noise-abatement approaches.

The pilots judged their degree of glide slope precision in part c of each of the four questionnaire statements. Regardless of the display/approach combinations that were compared, no fewer than six of the eight pilots judgments of their glide slope precision agreed with their actual performance. In statement 4d, all of the pilots selected the situation display over the command display as being more likely to cause descents below the glide slope during the transition from the upper to lower approach segment. For six of the eight pilots, this selection agreed with their actual performance. In questions 5 and 6, six of the eight pilots selected the standard approach with the command display as the most comfortable appraoch system, and the noise abatement approach with situation display as the most uncomfortable system. (The "most comfortable system" refers to the system that the pilot felt most at ease with.) Although two of the answers for each question were at variance, the majority opinion coincided with the quantitative data for the four display/approach conditions in that the mean height errors in MA 4 were greatest for the noise abatement approach with the situation display and least for the standard approach with the command display.

Questionnaire Comments

Responses to the "why?" portion of question 6 and to question 7 are paraphrased below.

1. Question 6: The reasons that two pilots felt that the noise-abatement approach with command display was the most uncomfortable were:

    a. Lack of pitch information.

    b. Lack of glide slope information.

    c. Inability to determine glide slope intercept point accurately.

2. Question 6: The reasons that the other six pilots felt that the noise-abatement approach with the situation display was the most uncomfortable were:

    a. Poor stabilization of aircraft prior to flare (2 pilots).

    b. Required more attention.

    c. Sink rate high requiring excessive power changes during transition to standard glide slope (2 pilots).

d. Wind shear correction more difficult.

3. Question 7: The pilots comments on the adequacy of the computerized night scene were:

   a. Excellent (1), very good (4), generally good (1), realistic and adequate (2).

Some responses in the comments section were:

1. Control forces were somewhat light for a DC-8.

2. Command display is superior, particularly in the noise-abatement approach because it eliminates the transition problem at low altitude, a potentially dangerous situation.

3. An airspeed indication should be included on the HUD.

4. Transition altitude from the 6° to the 3° glide slope is too low. Should be at 1000 ft.

5. Either noise-abatement approach is feasible provided the touchdown point is clearly visible at all times.

6. Command display is best because of smoother transitions and corrections to the glide slope.

RECOMMENDATIONS

These results suggest that glidepath control along the entire length of the approach path could be improved if the functions of both displays were incorporated into a single display. The command display would be used for guidance in the final phase of the landing approach, while the fixed-bar principle of the situation display would apply to the earlier portion of the approach. The two operating principles could be combined by incorporating into the center of the command display small horizontal bars fixed at −3° and −6° approach angles. These fixed bars should be unobtrusive relative to the flight path bar of the command display, yet be clearly perceptible so that the pilot could use the fixed bars for approach guidance as far down the approach as he desires.

CONCLUDING REMARKS

1. Performance with Zero Wind Conditions

   a. For both the standard and noise-abatement approaches, the mean height errors from the glide slope consistently decreased as the distance to the landing point was reduced.

   b. The glide slope intercept point was more difficult to determine with the command display than with the situation display.

   c. The situation display provided a significantly greater glidepath accuracy than the command display in the initial phase of both the standard and noise-abatement approaches.

d. Glidepath deviations were significantly less, although variability remained slightly larger, in the final phase of both types of approaches with use of the command display.

2. Performance under Wind Shear Conditions

a. A significant difference in operational capability between the two displays was seen when wind shear was a factor. The greater accuracy of the command display was demonstrated by the earlier reversal of the wind-shear-induced descent below the glide slope, the consequent lessening of flight path deviations from the glide slope, and a decreased variability in altitude control.

b. Use of the situation display in wind shear condition usually caused the simulated aircraft to exceed the FAA criteria limits for landing approach guidance systems in the final portion of the approach. This seldom occurred with use of the command display.

c. The pilot's recognition threshold for wind shear is not reached immediately following wind shear initiation and depends on the display being used.

3. Standard versus Noise Abatement Approaches

a. In all three sections of the approach path (initial, center, and final), and in both zero wind and wind shear conditions, the mean height errors from the glide slope and the standard deviations were greater for the noise-abatement approaches than those for the standard approaches.

b. The greater mean height errors for the noise-abatement approaches over the standard approaches in the terminal approach phase appear to be related to the higher mean glide slope angles recorded in the transition area of the noise-abatement approaches, particularly during the approaches with the command display.

c. No descents lower than 0.3° angular deviation below the glide slope were recorded during the transition to the standard glide slope in either type of noise-abatement approach.

4. Quantitative and Subjective Data Comparisons

a. A majority preference was expressed by the pilots for the command display. This agreed with the quantitative measures which showed the greater glide slope accuracy of the command display in the terminal phase of both types of approaches.

b. Pilot judgments of each display/approach condition correlated positively with their individual best performance in glide slope precision and least workload.

c. All of the pilots felt that the noise-abatement approach with the situation display was most likely to result in descents below the glide slope during transition from the upper to the lower approach segment.

d. Most of the pilots selected the standard approach with the command display as the most comfortable display/approach combination and the noise-abatement approach with the situation display as the most uncomfortable. This pilot preference agreed with the quantitative measures of best glide slope performance and least workload.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif. 94035, April 14, 1975

APPENDIX

PILOT QUESTIONNAIRE

Please complete the following statements. In items 1–4 insert one of the two approach systems named in parentheses. Your carefully considered opinions are extremely important to the outcome of this experiment, planned simulator and flight experiments, and to the future use by commercial air carriers of these and similar approach systems in actual flight. Base all your opinions on the approach systems as they were presented to you in the simulator. A comments section is included at the end of the questionnaire to clarify, qualify, add, etc., any opinions or statements that you desire.

1. (Situation, command)

   a. During *standard approaches*, I preferred the __________________________ display.

   b. During *standard approaches*, the __________________________ display required less control manipulations to maintain my desired proximity to the glide slope.

   c. I was able to maintain a greater degree of glide path precision with the __________________________ display during *standard approaches*.

2. (Standard approach with situation display, noise-abatement approach with situation display)

   a. I preferred the __________________________ landing approach.

   b. The __________________________ landing approach required less control manipulations to maintain my desired proximity to the glide slope.

   c. I was able to maintain a greater degree of glide path precision in the __________________________ landing approach.

3. (Standard approach with command display, noise-abatement approach with command display)

   a. I preferred the __________________________ landing approach.

   b. The __________________________ landing approach required less control manipulations to maintain my desired proximity to the glide slope.

   c. I was able to maintain a greater degree of glide path precision in the __________________________ landing approach.

4. (Situation, command)

   a. I preferred the noise-abatement approach with the __________________________ display.

b. The noise-abatement approach with the ______________________ display required less control manipulations to maintain my desired proximity to the glide slope.

c. I was able to maintain a greater degree of glidepath precision in the noise-abatement approach with the ____________________ display.

d. Descents below normal glide slope limits during the transition from the upper to lower segment were more likely in the noise-abatement approach with the ______________ ______ display.

5. The most comfortable approach system combination for me was:

6. The most uncomfortable approach system combination for me was:

Why?

7. Please state your opinion as the adequacy of the computerized night scene.

COMMENTS:

REFERENCES

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4. Bourquin, K.; Palmer, E. A.; Cooper, G.; and Gerdes, R. M.: Initial Flight and Simulator Evaluation of a Headup Display for Standard and Noise Abatement Visual Approaches. NASA TM X-62,187, 1973.

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6. Palmer, E. A.; and Cronn, F. W.: Headup Displays for STOL Visual Approaches. NASA SP-320, 1972, pp. 227–243.

7. FAA: Federal Aviation Agency Criteria for Approval of Category II Landing Weather Minima. Advisory Circular 120-20, Appendix 1, 5-6, June 6, 1966.

TABLE 1.– PRESENTATION ORDER OF DISPLAY/APPROACH CONDITIONS

Pilot	Order of presentation			
	1st	2nd	3rd	4th
1	SS	SC	NS	NC
2	SS	SC	NS	NC
3	SS	SC	NS	NC
4	SS	SC	NS	NC
5	SC	SS	NC	NS
6	SC	SS	NC	NS
7	SC	SS	NC	NS
8	SC	SS	NC	NS

Display/Approach Conditions

SS ____________ Standard approach with situation display.
SC ____________ Standard approach with command display.
NS ____________ Noise-abatement approach with situation display.
NC ____________ Noise-abatement approach with command display.

TABLE 2.– MEAN ABSOLUTE HEIGHT ERRORS UNDER ZERO WIND CONDITIONS FOR THE COMMAND AND SITUATION MODES IN EACH OF THE MEASUREMENT AREAS (N = EIGHT)

MA	Situation display		Command display	
	Mean (m)	SD (m)	Mean (m)	SD (m)
	Standard approaches			
1a	4.28	1.16	8.69	6.33
2a	2.72	.58	3.25	2.12
4	1.36	.32	1.15	.38
	Noise-abatement approaches			
1	7.32	4.03	22.21	18.94
2	5.40	4.20	14.59	14.42
4	2.04	.42	1.69	.64

TABLE 3.– MEAN ABSOLUTE HEIGHT ERRORS FOR THE COMMAND AND SITUATION DISPLAYS UNDER ZERO WIND AND TAIL WIND SHEAR CONDITIONS IN MEASUREMENT AREA FOUR (N = EIGHT)

Condition	Situation display		Command display	
	Mean (m)	SD (m)	Mean (m)	SD (m)
Zero wind	1.70	0.52	1.42	0.60
Wind shear	2.86	.64	2.02	.46

TABLE 4.– MEAN ABSOLUTE HEIGHT ERRORS FOR STANDARD AND NOISE ABATEMENT APPROACHES UNDER ZERO WIND AND TAIL WIND SHEAR CONDITIONS IN MEASUREMENT AREA FOUR (N = EIGHT)

Condition	Standard approaches		Noise abatement approaches	
	Mean (m)	SD (m)	Mean (m)	SD (m)
Zero wind	1.25	0.36	1.87	0.59
Wind shear	2.20	.64	2.62	.77

TABLE 5.– SUMMARY OF PILOT QUESTIONNAIRE DATA

Pilot	Statements														
	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c	4d	5	6
1	(SC)	SS	(SC)	SS	(NS)	SS	(SC)	NC	(SC)	(NC)	NS	(NC)	(NS)	SC	NC
2	(SC)	(SC)	(SC)	(NS)	NS	(NS)	NC	(NC)	NC	(NC)	(NC)	(NC)	(NS)	NC	NS
3	(SC)	SC	(SC)	(SS)	(SS)	(SS)	SC	(SC)	SC	(NC)	NS	(NC)	NS	SC	NS
4	(SC)	(SC)	(SC)	(SS)	(SS)	(SS)	(SC)	(SC)	(SC)	(NC)	(NC)	(NC)	(NS)	SC	NS
5	SS	(SS)	SS	SS	(NS)	NS	(NC)	(NC)	(NC)	NS	(NS)	NS	NS	NS	NC
6	(SC)	(SC)	(SC)	(SS)	SS	(SS)	(SC)	(SC)	(SC)	NC	NC	NC	(NS)	SC	NS
7	(SC)	SC	(SC)	NS	(SS)	(SS)	NC	(SC)	(SC)	(NC)	NC	(NC)	(NS)	SC	NS
8	(SC)	SC	(SC)	(SS)	(SS)	(SS)	(SC)	(SC)	(SC)	(NC)	(NC)	(NC)	(NS)	SC	NS

Key

SS – Standard approach with Situation Display
SC – Standard approach with Command Display
NS – Noise abatement approach with Situation Display
NC – Noise abatement approach with Command Display

Entries in parentheses indicate agreement between a pilot's performance and his questionnaire response for statements 1 to 4.

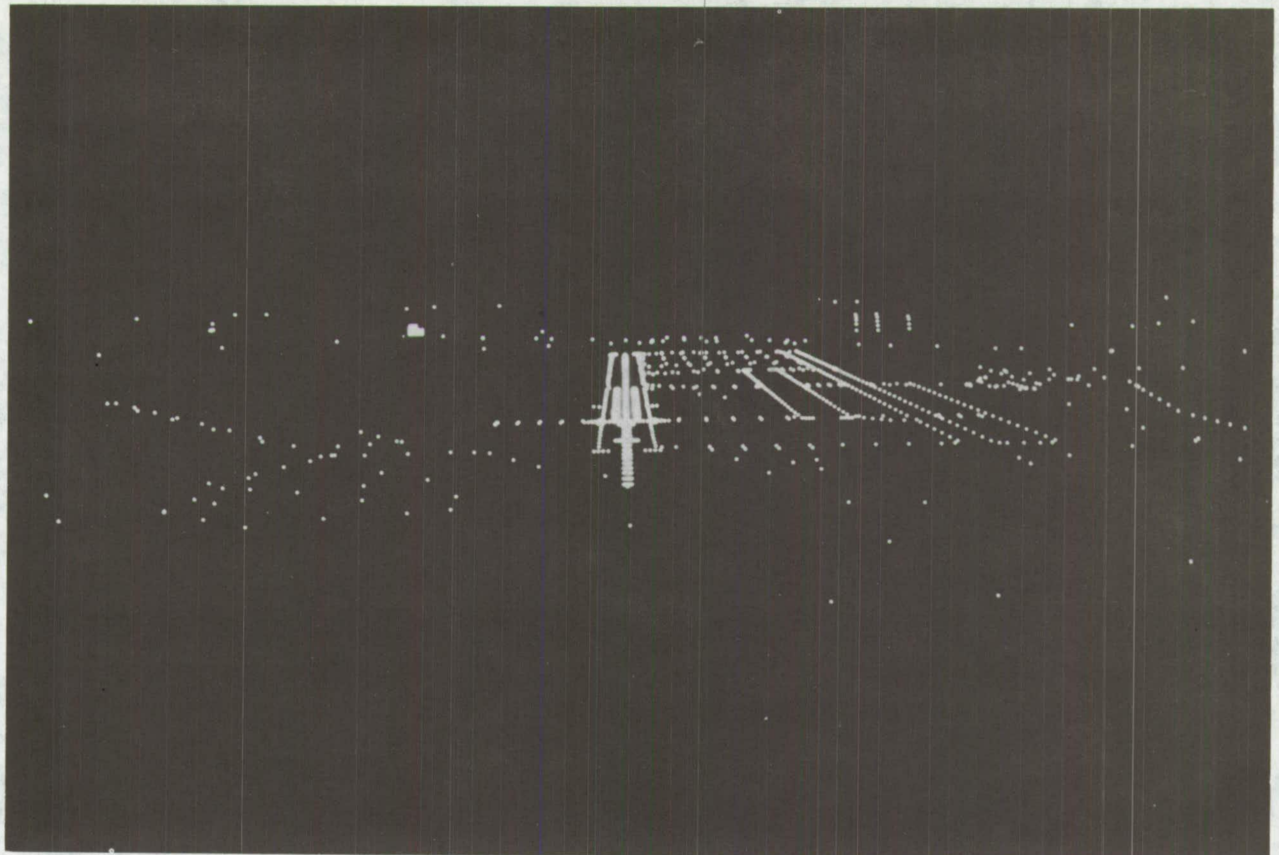

Figure 1.– Computer generated night scene of municipal airport at San Jose, California.

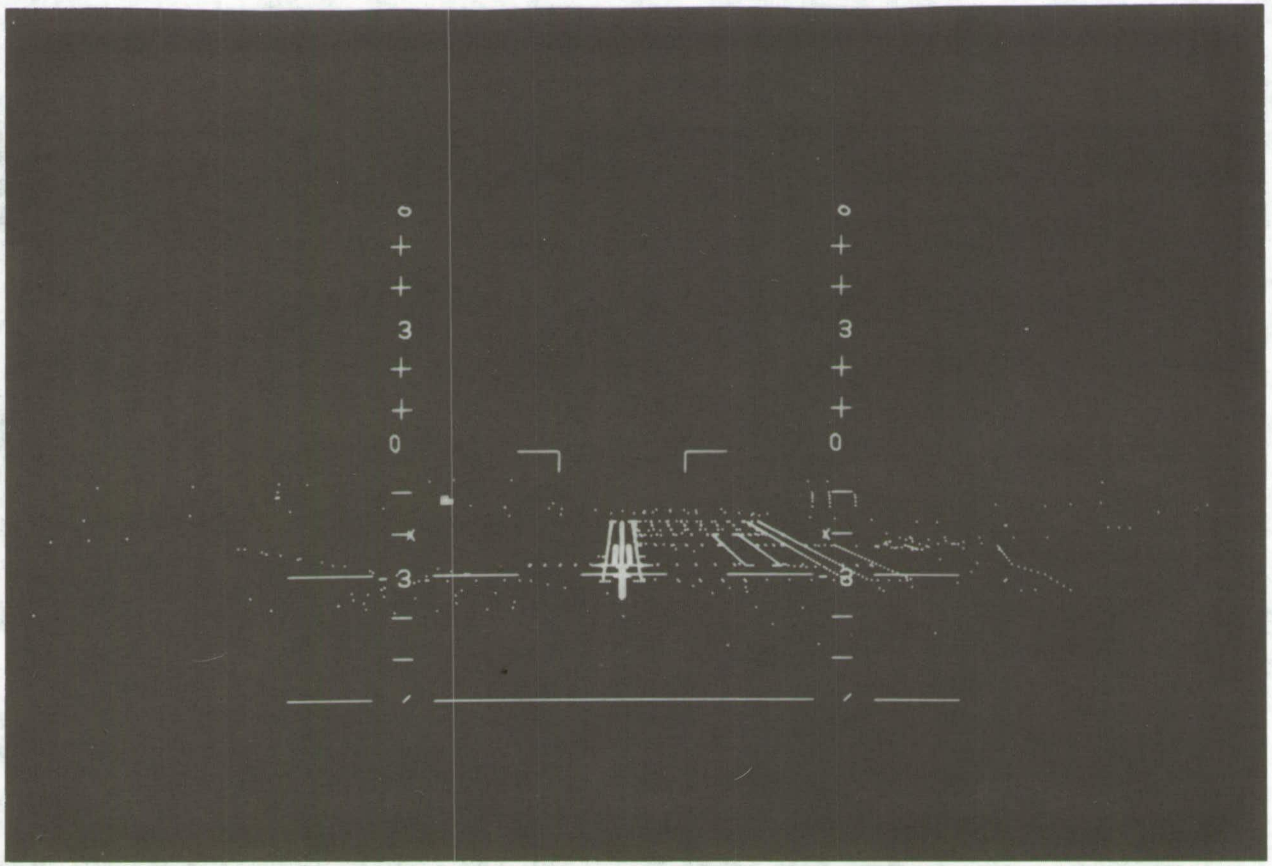

Figure 2.– Computer generated head-up situation display overlaying night scene of airport.

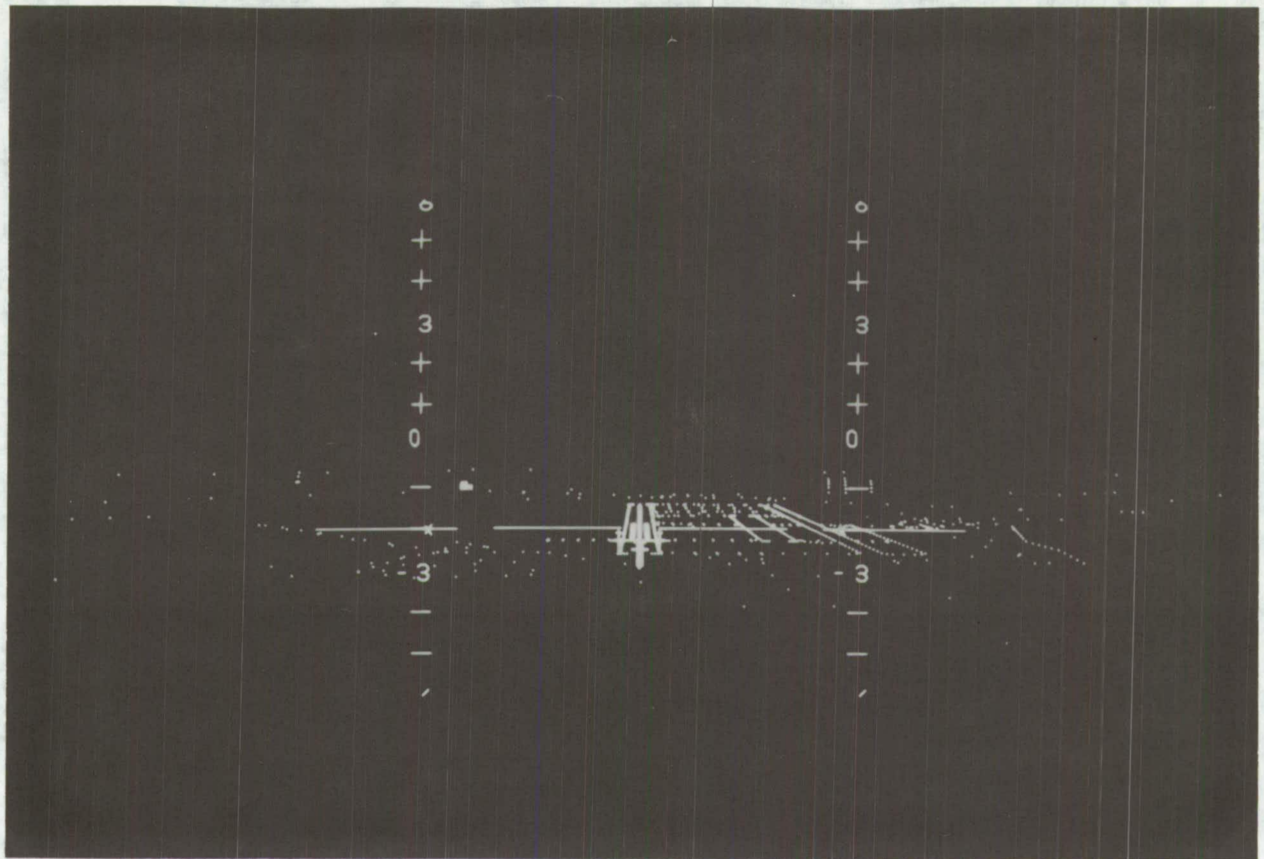

Figure 3.– Computer generated head-up command display overlaying night scene of airport.

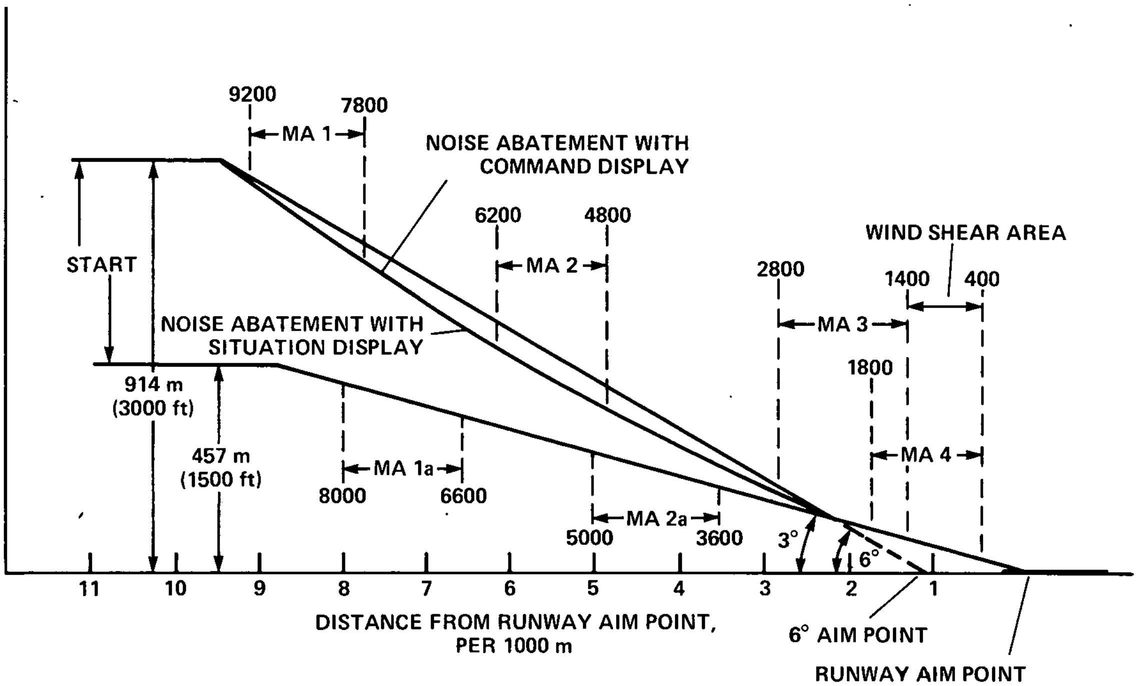

Figure 4.– Landing approach profiles and the associated measurement areas (MAs).

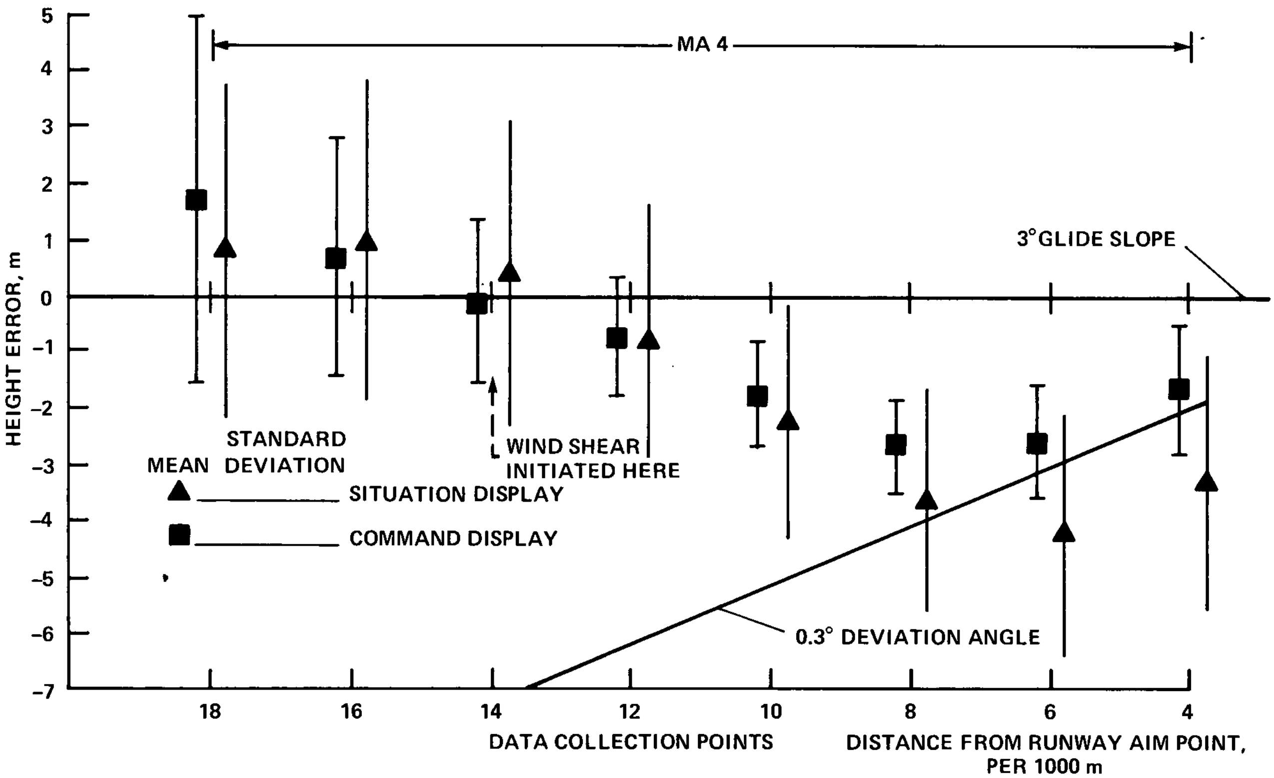

Figure 5.– Mean true height errors and standard deviations obtained at each data collection point during approaches encountering wind shear in measurement area four.

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